

# **Validation of the TOLNet Lidars during SCOOP (Southern California Ozone Observation Project) using In-house and Centralized Data Processing**

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- **Core participants: 5 tropospheric ozone lidars from TOLNet**
  - **AMOLITE** from Environment and Climate Change Canada, PI: K. Strawbridge
  - **LMOL** from NASA Langley Research Center, PI: Tim Berkoff
  - **TMT** from Jet Propulsion Laboratory at TMF, PI: T. Leblanc
  - **TOPAZ** from NOAA-Earth System Research Laboratory, PIs: C. Senff and A. Langford
  - **TROPOZ** from NASA-GSFC, PIs: T. McGee and J. Sullivan
- **Other contributors:**
  - M. Newchurch (Univ. Alabama, Huntsville): Campaign refereeing support
  - S. Kuang (Univ. Alabama, Huntsville): Campaign refereeing support
  - M. Johnson (NASA AMES): Modeling support
  - B. Lefer and J. Kaye (NASA HQ): Campaign funding support
- **Measurements and deployment:**
  - 5 x 50+ hours spread over 7 nights and days (incl. approx. 20 hours nighttime)
  - 18 ECC ozonesondes launched by JPL-TMF group (1 to 6 launches per day)
  - 5 x 24/7 surface ozone measurements
  - 10+ hours of other lidar measurements from JPL-TMF  
(water vapor, stratospheric ozone and temperature, ceilometer)

## All available 30-minutes-long lidar-ozonesonde-coincident profiles:

Coincidence criterion: First 30 minutes of each launch (+/- a few minutes)

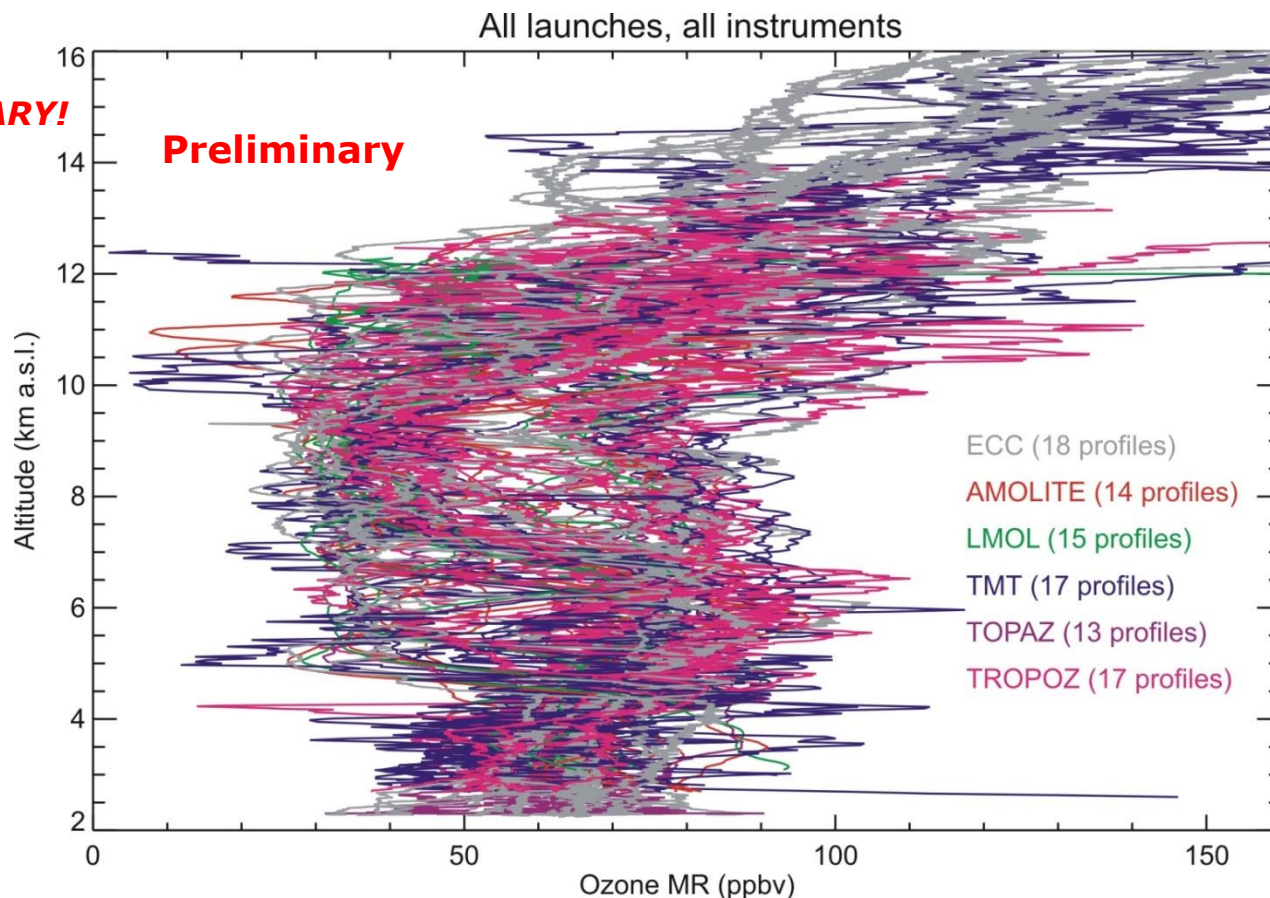
### NOTE:

**Today: showing only SCOOP**  
**"Level 2" data, i.e., PRELIMINARY!**

The validated version ("SCOOP Level 3") will come out soon

### Figure shows:

- Geophysical variability throughout campaign
- Extent of valid range for the various lidars
- Spread of measurements
- 18 launches but not as many coincident lidar profiles due to logistical and operational constraints



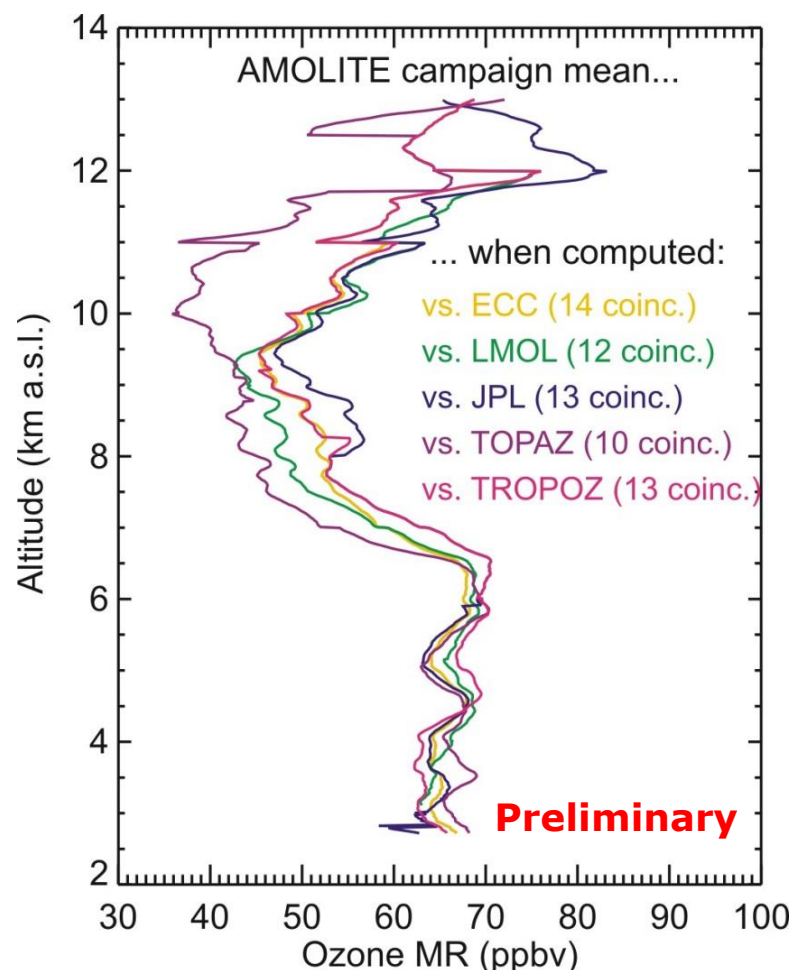
➔ The rest of this work will show validation results using these **PRELIMINARY SCOOP DATA ONLY** and these coincidences only

## Are all instruments measuring the same atmosphere at the same time?

**Figure shows example of AMOLITE "Campaign Mean" profiles against different coincident instruments:**

- "Campaign mean" is different whether it is compared against one instrument or another
- This combination of operational and geophysical constraints should be taken into account when interpreting observed discrepancies between 3 or more instruments

**Only 7 ECC launches during which all 5 lidars operated simultaneously**



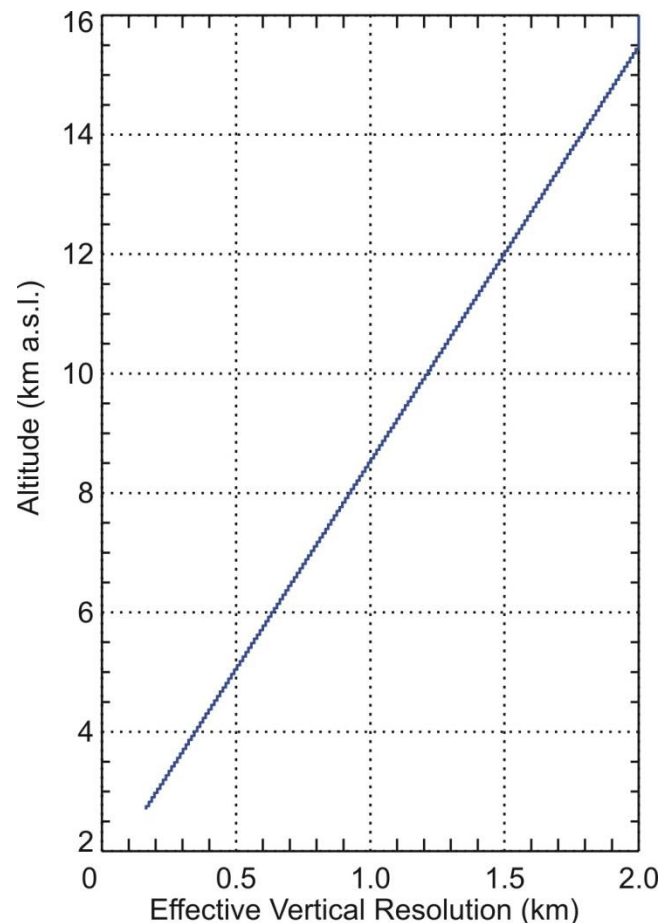
**→ Instruments will be compared with each other, but using one-to-one instrument coincidences in order to maximize comparison statistics**

## Do all instruments have the same capability to resolve thin vertical structures?

→ For this study, all lidar and ECC data were processed to yield the same vertical resolution:  
The “SCOOP vertical resolution scheme”

### Figure shows SCOOP vertical resolution

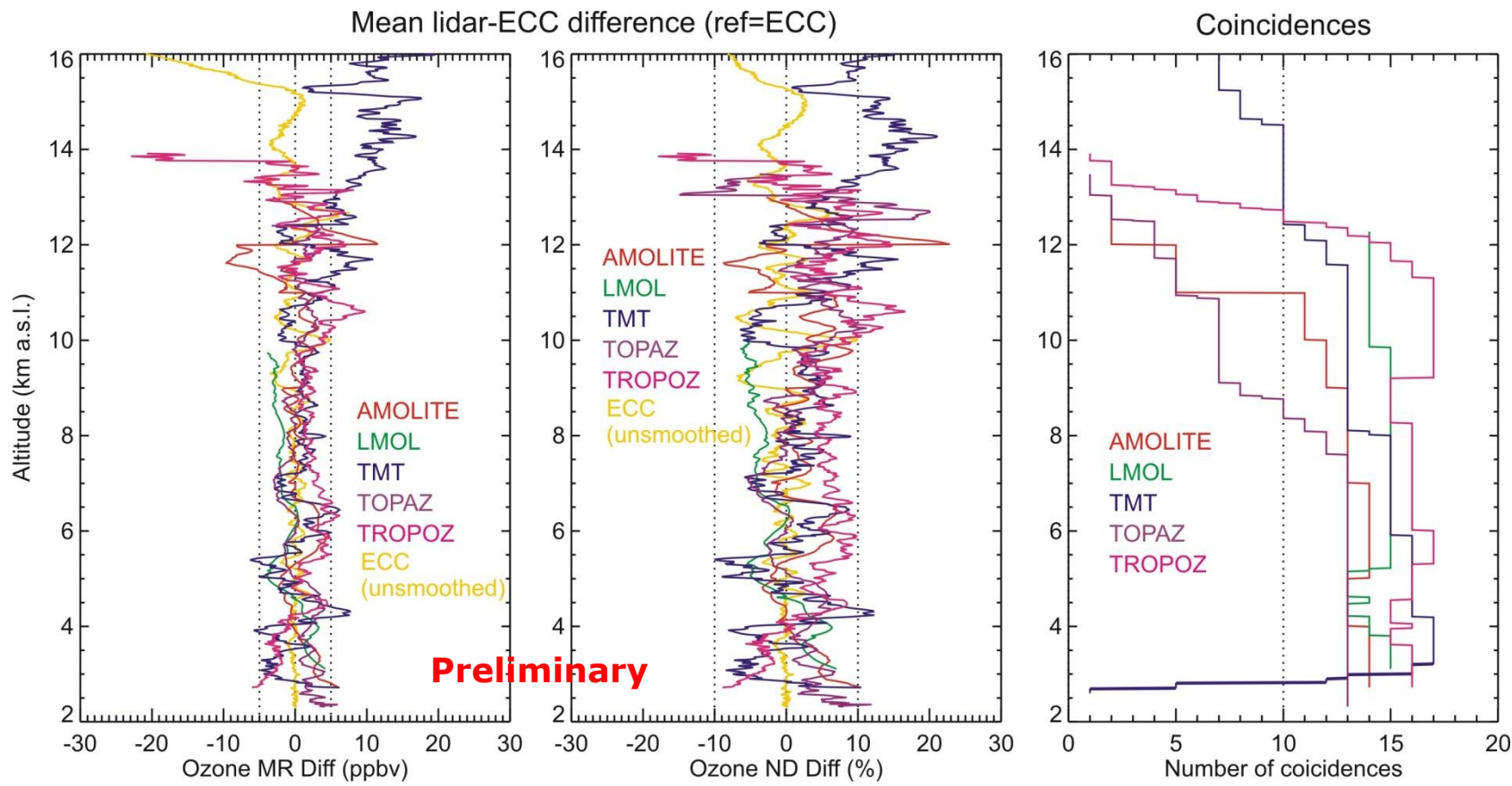
- Use NDACC-Standardized recommended definition (Leblanc et al., Atmos. Meas. Tech., 2016)
- 200-m at the surface, 1.5 km at 12 km a.s.l.
- The actual averaging kernels (AK) are not identical for all lidars and ECC: they take into account each instrument sampling resolution (from 3.75 m to 15-m)



→ **Caveat: the quality of the profiles is NOT optimized for all lidar instruments (e.g., TMT near-field, details later)**



One-to-one instrument comparisons composited together against ECC ozonesonde



- All instruments:**
- Below 10 km: within 5 ppbv or 10% of each other
  - A few exceptions above 10 km, due to poor stats (less coincidences) and possibly geographical mismatch

**This ends our “traditional approach”  
to validate the TOLNet lidars**

**Now, let’s use centralized data processing  
for further validation**

**Several efforts made over the past 5-10 years towards centralized data processing for lidar networks:**

**EARLINET (aerosols), NDACC (ozone depletion), GRUAN (climate),  
and now TOLNet (AQ)**

## **Advantages:**

*Standardized processing*

➔ *Maximizes comparability (for both products and their uncertainty)*

*Robust processing*

➔ *Facilitates Near-Real-Time delivery of homogeneous network-wide measurements*

*Alternate to in-house processing*

➔ *Facilitates identification and separation of instrumental and algorithm errors*

## **Caveats:**

*Standardized processing*

➔ *Can lead to non-optimized results if network instruments are too heterogeneous*

*Centralized processing*

➔ *Potential to lose traceability if no effort for transparency is made*

**➔ The rest of this work reports on the first (and preliminary) results from the TOLNet centralized data processing to compare and validate the TOLNet lidars**



# In what way can centralized data processing help?

**With centralized data processing, uncertainty budgets of all lidars can be compared on a common basis**

**Use of NDACC-recommended standardized uncertainty budget**

(Leblanc et al., Atmos. Meas. Tech., 2016)

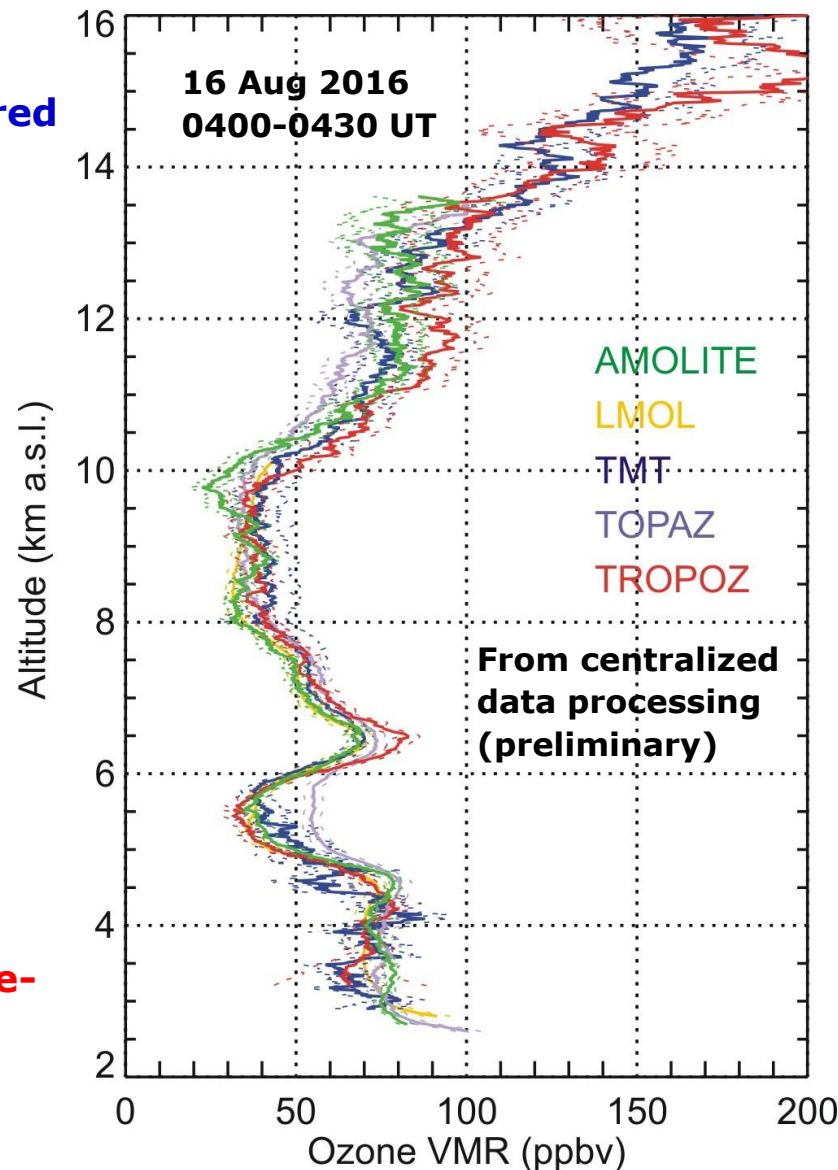
## Figure shows:

- **Preliminary** 30-min sonde-coincident profiles produced using centralized data processing for all 5 lidars
- Measurement start Aug 16 at 0400 UT (nighttime)
- All lidars yield same "SCOOP" vertical resolution
- +/- uncertainty shown with thin dotted lines

## Not shown:

Differences between centralized and in-house are within +/-10% for most lidars everywhere below 10 km

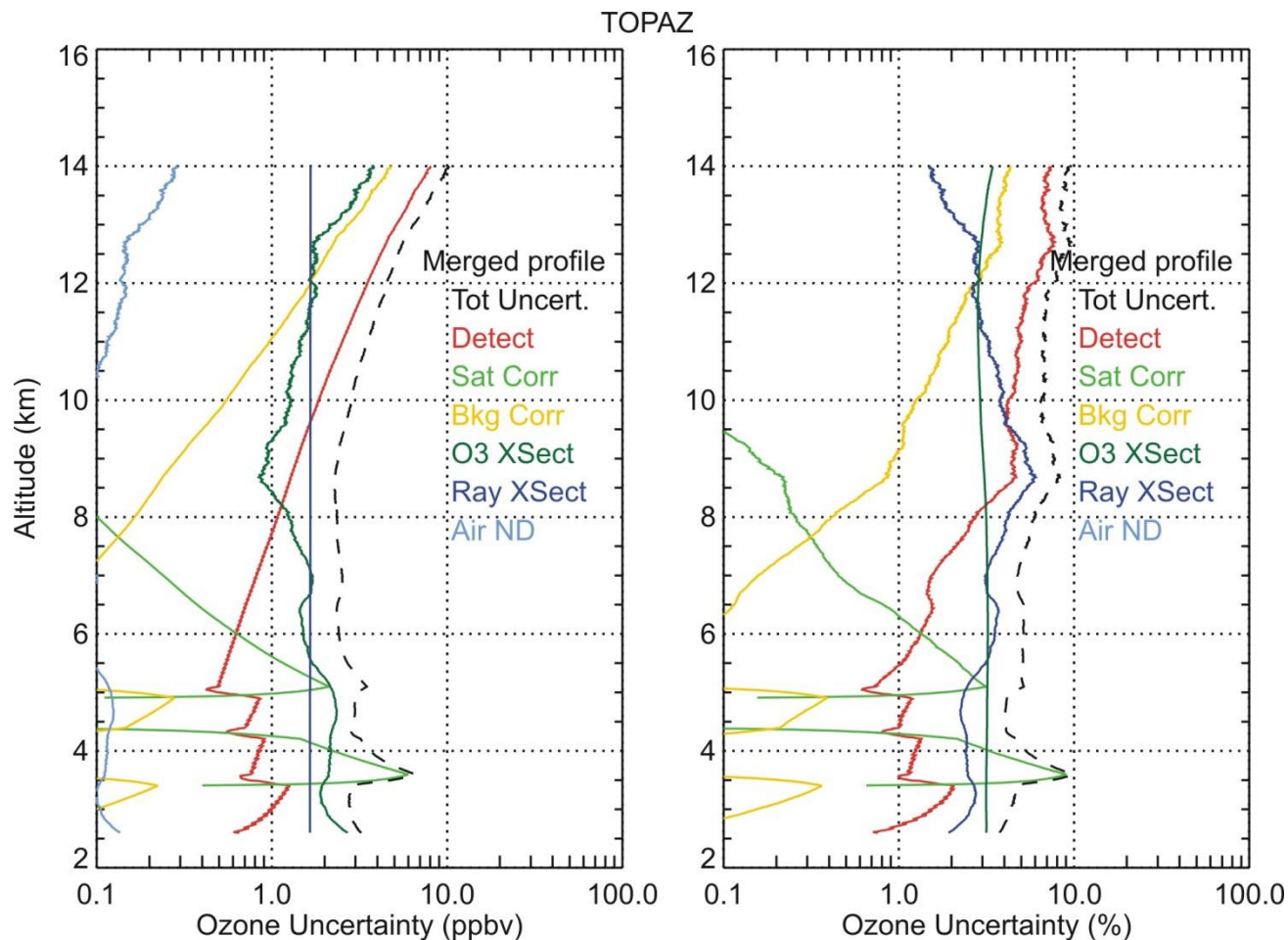
**→ Use of centralized data processing adequate enough to inter-compare the 5 TOLNet lidars' uncertainty budgets (next slides)**



## TOPAZ example:

### Figure shows:

- 6 uncertainty components (colored curves)
- Black dash curves show combined uncertainty
- 4 different components have major impact on total uncertainty, at different altitudes
- All estimates are preliminary



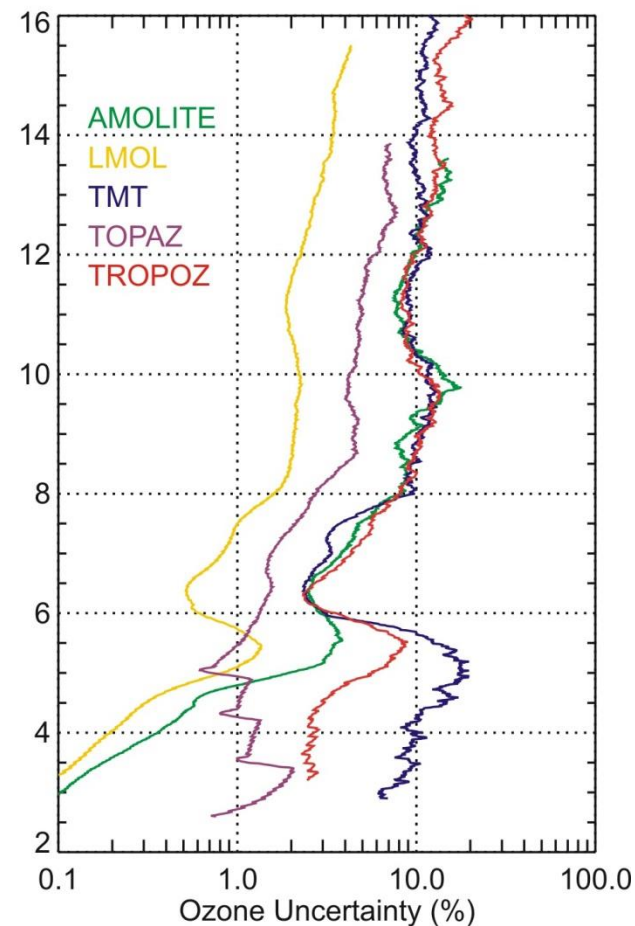
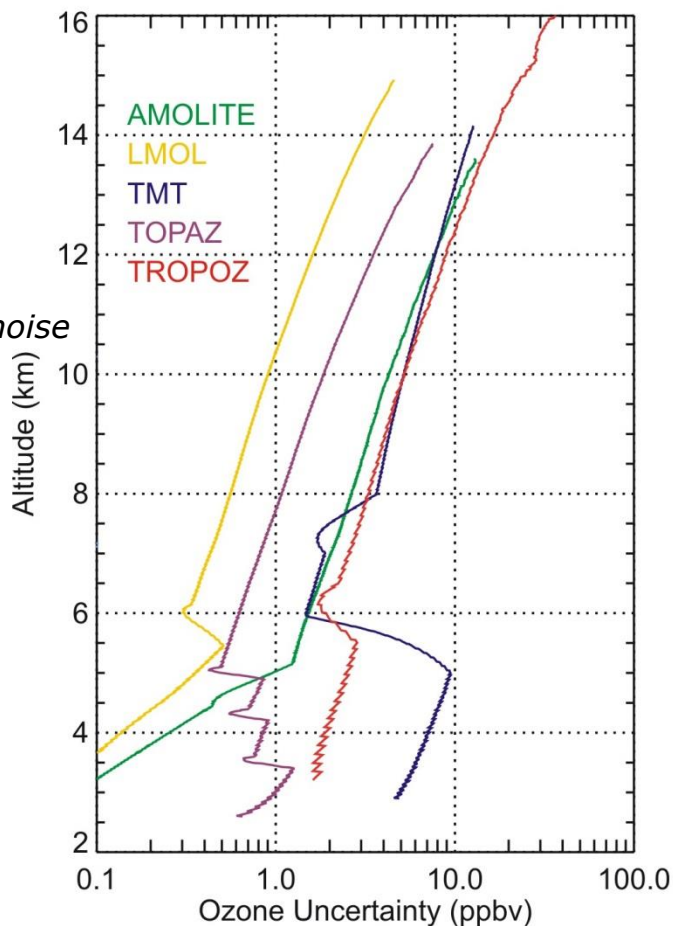
→ Individual uncertainty components, for all lidar, will be shown next

## Detection noise:

Uncertainty source: Detection noise

### Figure shows:

- Large range of values
- Higher laser rep. rates (LMOL, TOPAZ) yield lower detection noise
- TMT detection noise uncert. highest for altitudes below 6 km due to inadequate SCOOP vertical resolution applied to near-field low STNR
- All estimates are preliminary

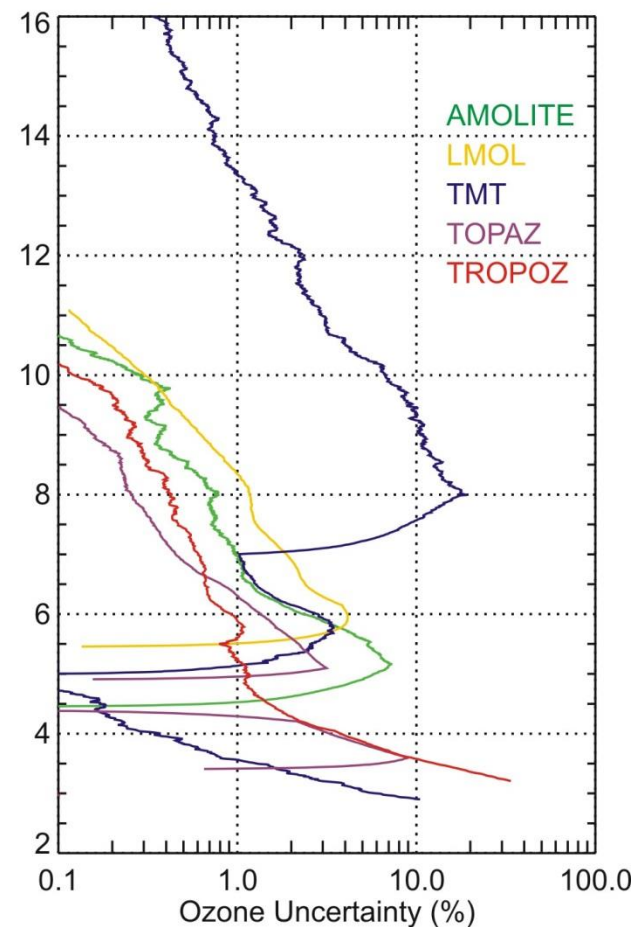
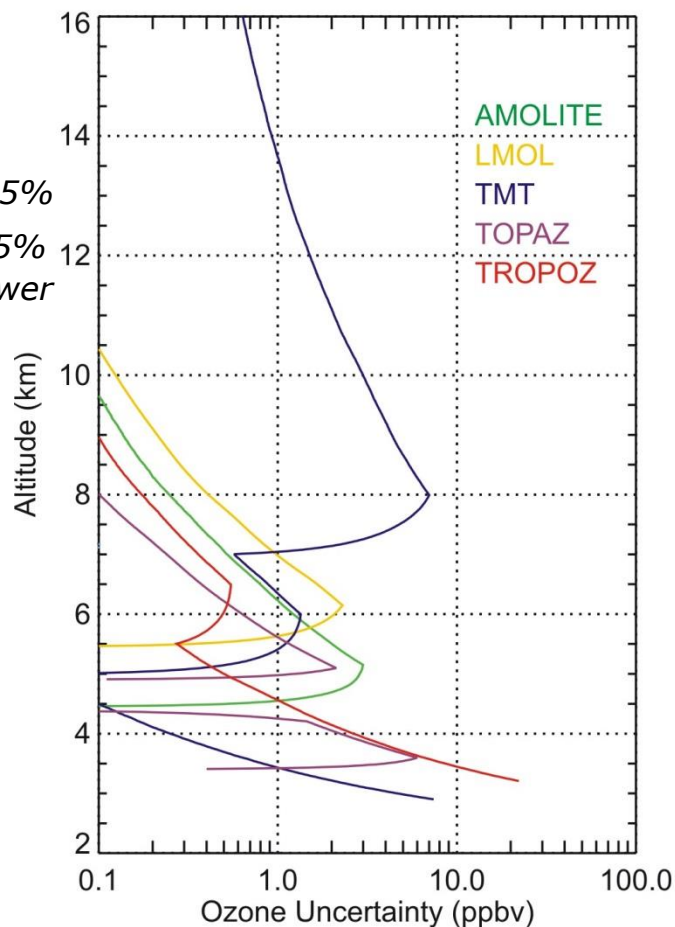


## Saturation (pile-up):

Uncertainty source: Saturation (pile-up) correction uncertainty  
(assuming 10% dead-time uncertainty)

### Figure shows:

- Values remain typically below 5%
- Exception for TMT, reaching 15% (strong signal optimized for lower stratosphere)
- All estimates are preliminary



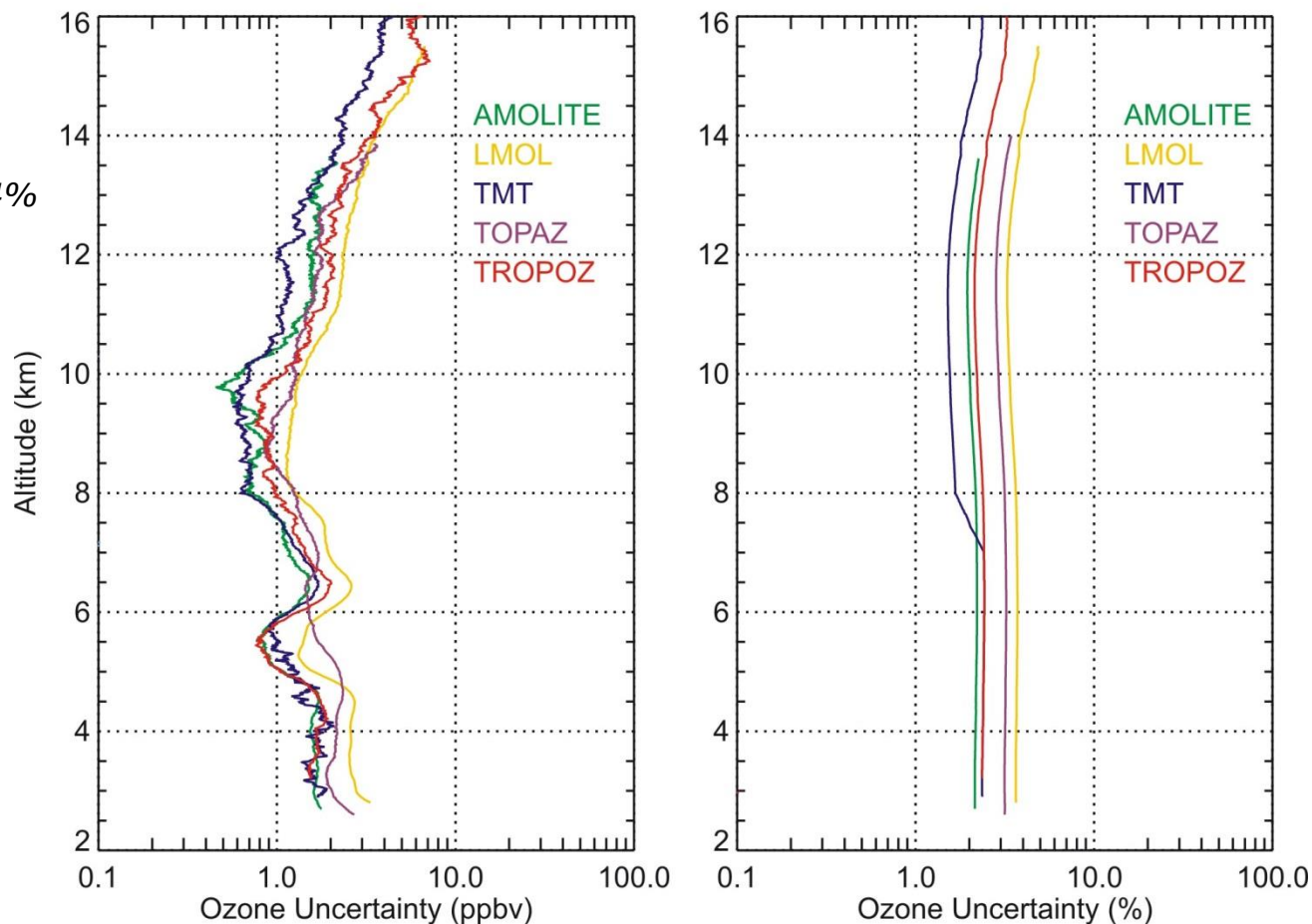


### O3 absorption cross-section:

Uncertainty source: Ozone absorption cross-section differential  
(assuming 1-5% cross-section uncertainty, see Weber et al., 2016)

#### Figure shows:

- All lidars in the order of 2%-4%
- 2%-4% is the minimum uncertainty we should expect from all instruments
- All estimates are preliminary



Ref: Weber, M., et al.: Uncertainty budgets of major ozone absorption cross sections used in UV remote sensing applications, Atmos. Meas. Tech., 9, 4459-4470, 10.5194/amt-9-4459-2016, 2016.

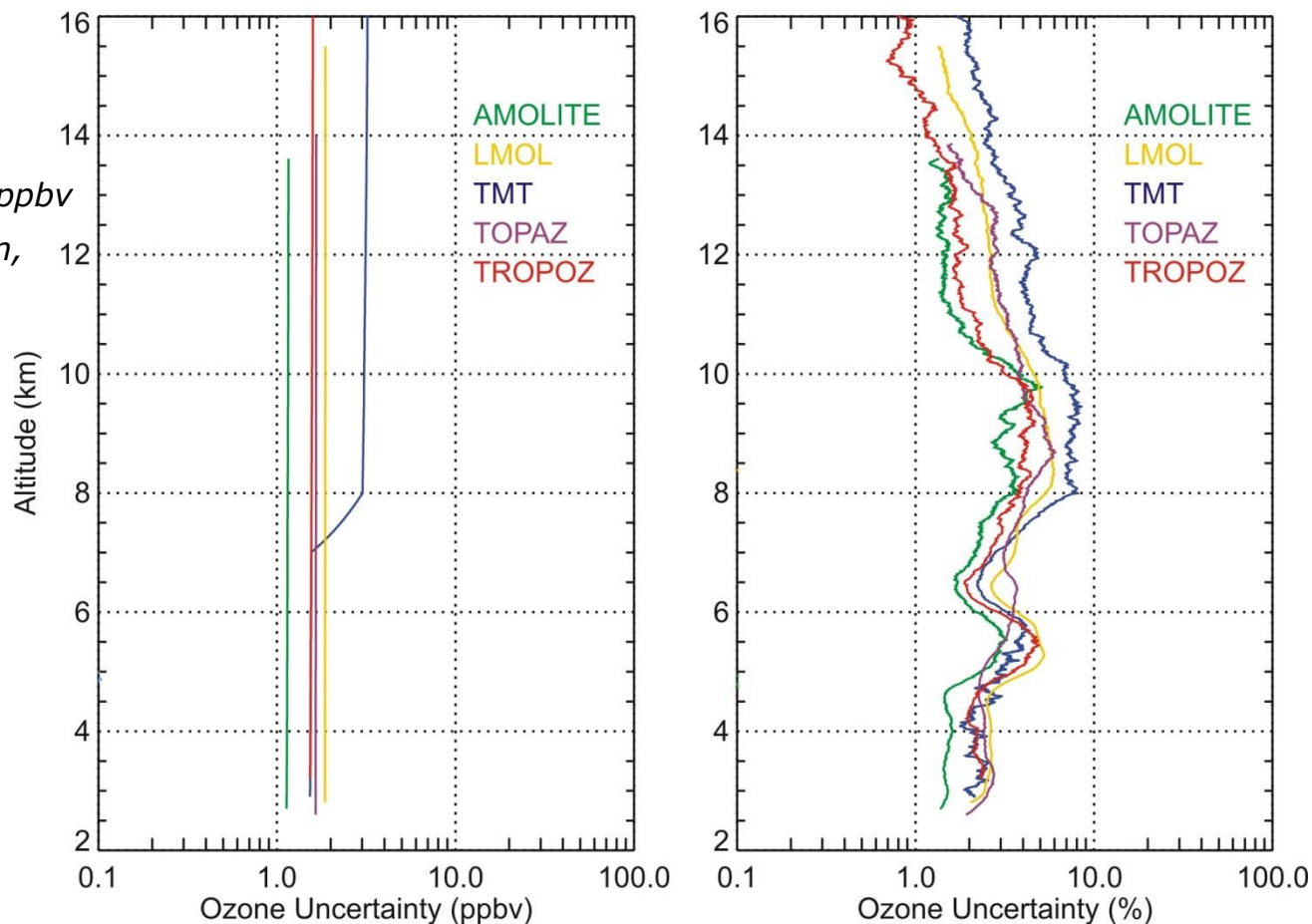


## Rayleigh cross-sections:

Uncertainty source: Rayleigh extinction cross-section differential  
 (assuming 2% Rayleigh cross-section uncertainty, see Eberhard, 2001)

### Figure shows:

- All lidars: in the order of 1-2 ppbv
- Exception for TMT above 8 km, in this case due to the use of a 299/355 nm DIAL pair
- All estimates are preliminary

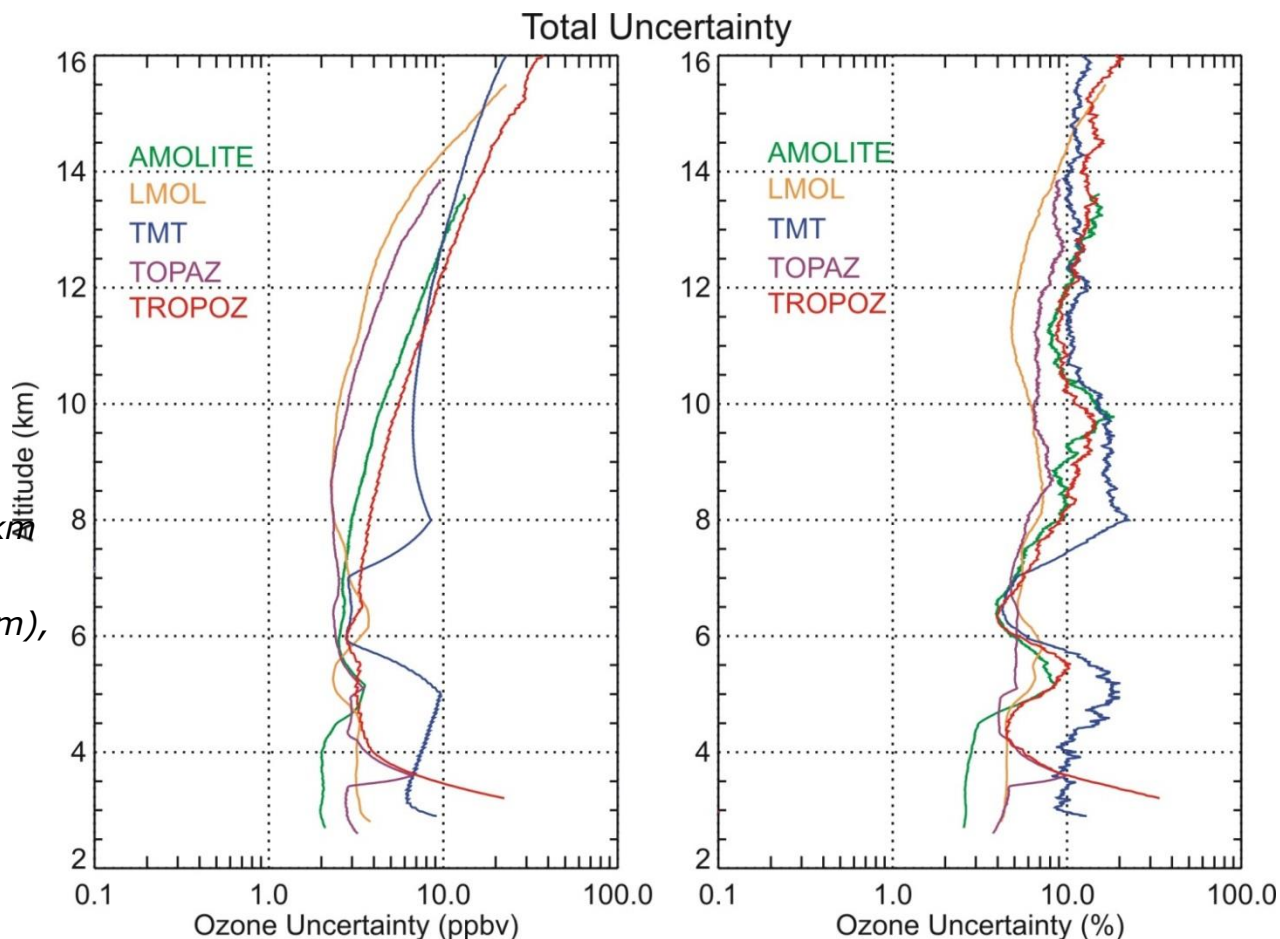


Eberhard, W. L.: Correct equations and common approximations for calculating Rayleigh scatter in pure gases and mixtures and evaluation of differences, Appl. Opt., 49, 1116-1130, 10.1364/ao.49.001116, 2010.

## Total uncertainty, all 5 lidars:

### What the figure shows:

- Total uncertainties range between 2 ppbv/2% and 4 ppbv/10% for all lidars below 12 km
- Exception is for TMT, with localized peaks at 5 km and 8 km
- TMT higher uncertainty due to low STNR in the near-field (5 km), and inadequate SCOOP vertical resolution forcing transition to far-field in a region of strong signal saturation (8 km)
- All estimates are preliminary



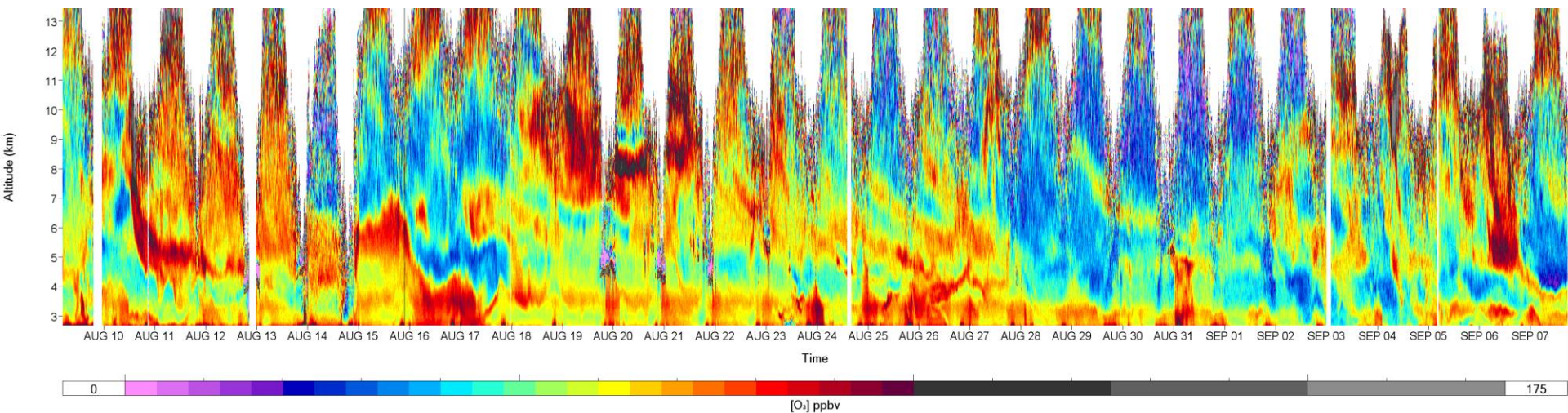
➔ All uncertainty estimates match very well the lidar-lidar and lidar-sonde differences observed during SCOOP

➔ Present budget also highlights the need to apply instrument-dependent vertical resolution schemes in order to optimize final product ➔ SCOOP Data Level 3 !...

- **SCOOP campaign took place Aug 10-16, 2016**
- **Objective was to validate the tropospheric ozone measurements of 5 of the 6 TOLNet lidars**
- **Campaign was very successful: 5 x 50+ hours, 18 ozonesonde launches**
- **All preliminary (“Level 2”) lidar data were validated beyond expectation**
- **Lidar-lidar and lidar-sonde show differences not exceeding 10% in most cases and at most altitudes below 12 km**
- **Centralized data processing confirmed that observed differences remain within all reported uncertainties**
- **TOLNet centralized data processing algorithm development will continue, in parallel with the refinement of the in-house algorithms**
- **TOLNet is now ready to produce optimized SCOOP Level 3 data, with nominal vertical resolution, and standardized uncertainty budgets**
- **“Level 3” data will be publicly available and used for science studies**

## AMOLITE Lidar, 31 days stationed at TMF (first 10 days are SCOOP)

*Courtesy of K. Strawbridge*





THANK YOU



**Thank you to the 1,000 Firefighters who saved the community of Wrightwood, CA on the day the SCOOP Campaign was cut short due to the BlueCut Fire Evacuation**

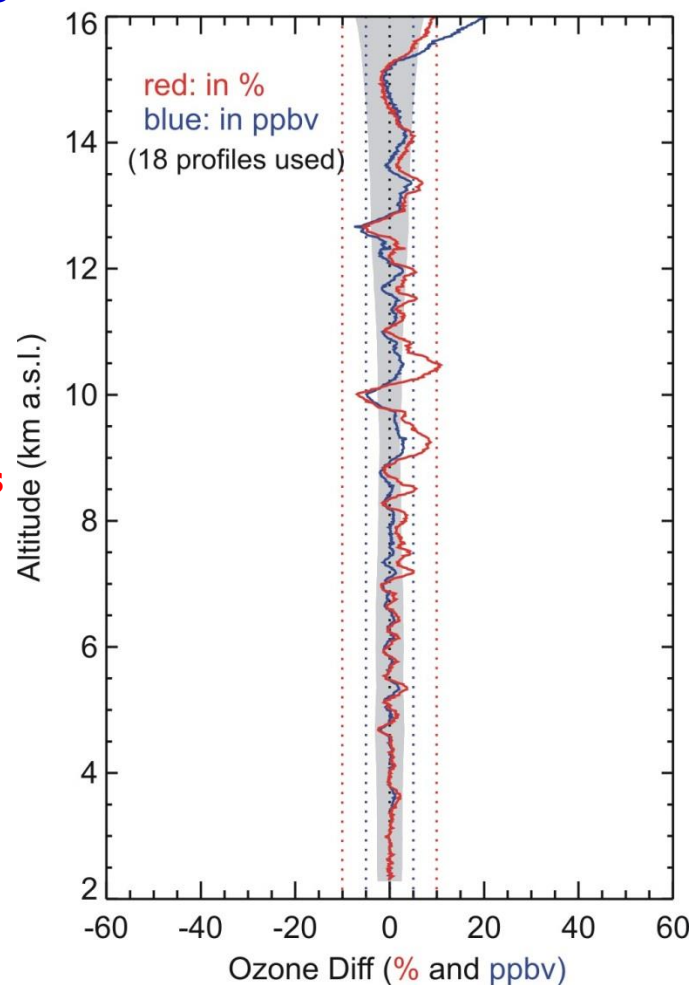


## BACK UP SLIDES

**Difference between ECC with and ECC without AKs provides a measure of additional noise to expect when vertical resolution is not standardized**

**→ With the SCOOP vertical resolution scheme, we spare ourselves an additional +/-5 ppbv or +/-10% additional noise in the comparisons**

Mean ozone difference between ECC with and without Averaging Kernels

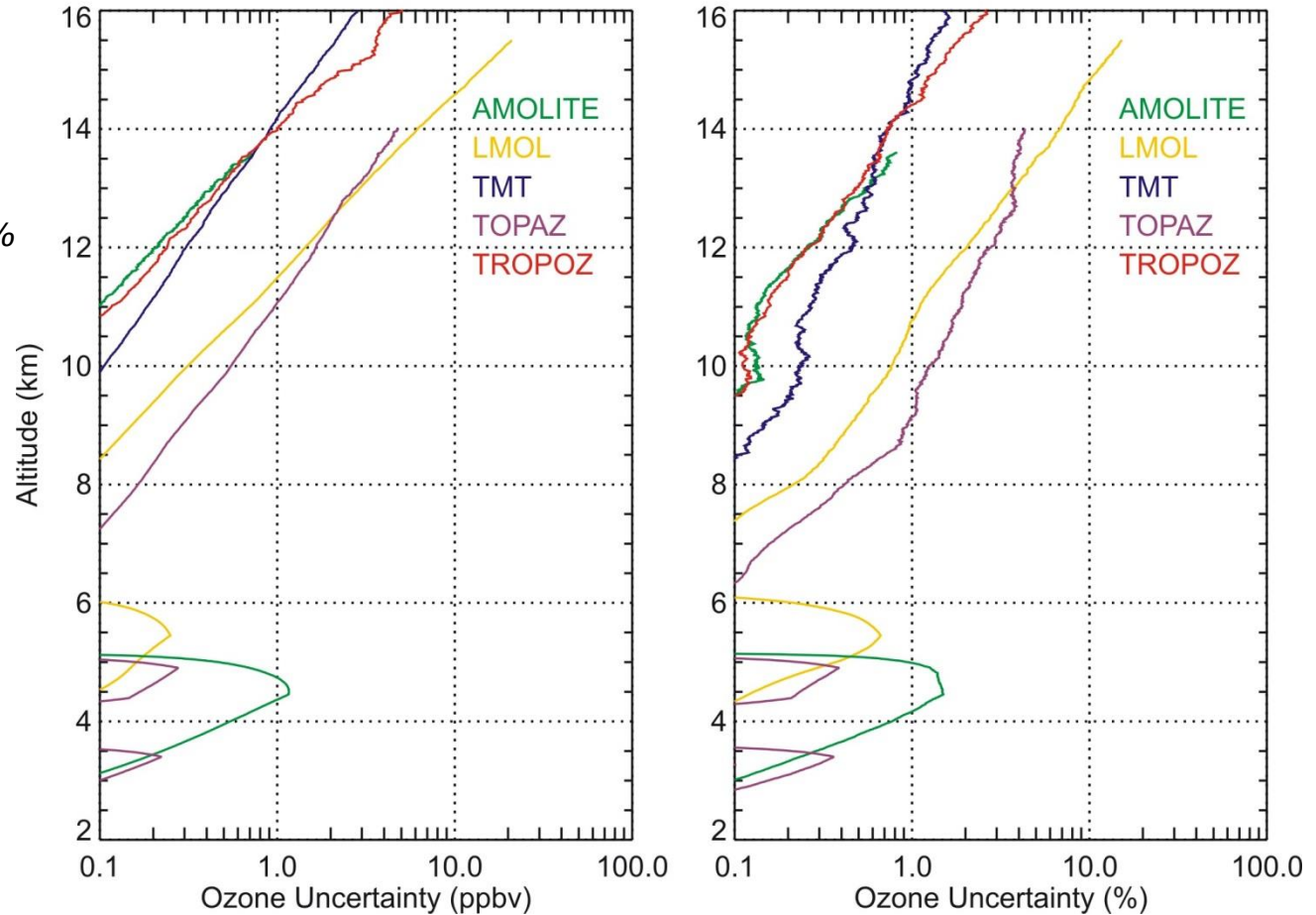


## Background noise extraction:

### Figure shows:

- All remain below 2%
- Exception for TOPAZ up to 4% at highest altitudes
- All estimates are preliminary

Uncertainty source: Background correction uncertainty

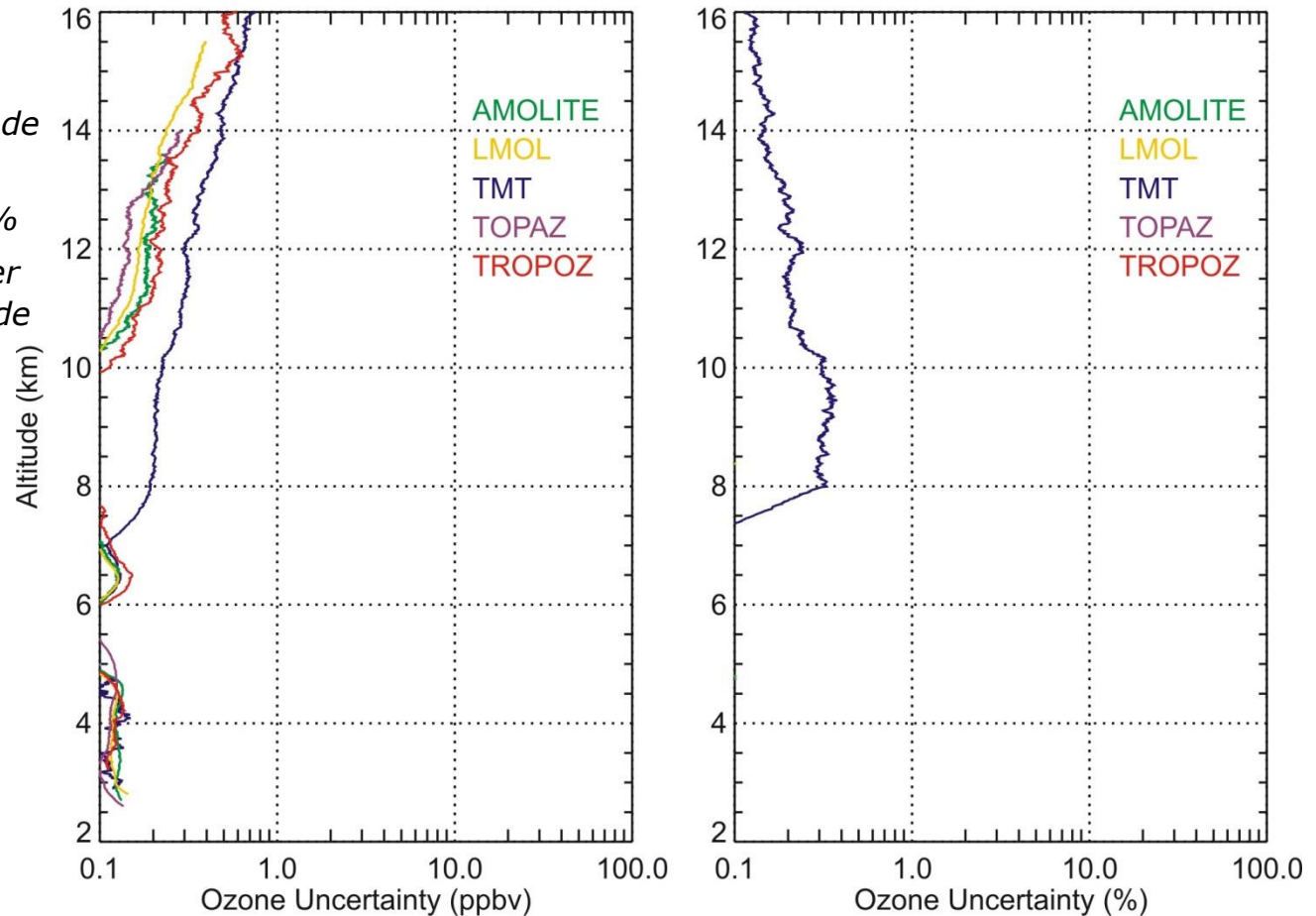


## Air number density:

Uncertainty source: Air number density uncertainty  
 (assuming 0.3 hPa and 0.5 K radiosonde pressure and temperature uncertainty respectively)

### Figure shows:

- Best case scenario: use of sonde temperature and pressure
- All lidars below 1 ppbv or 0.3%
- Expect estimate to be 4x larger if using models instead of sonde
- All estimates are preliminary

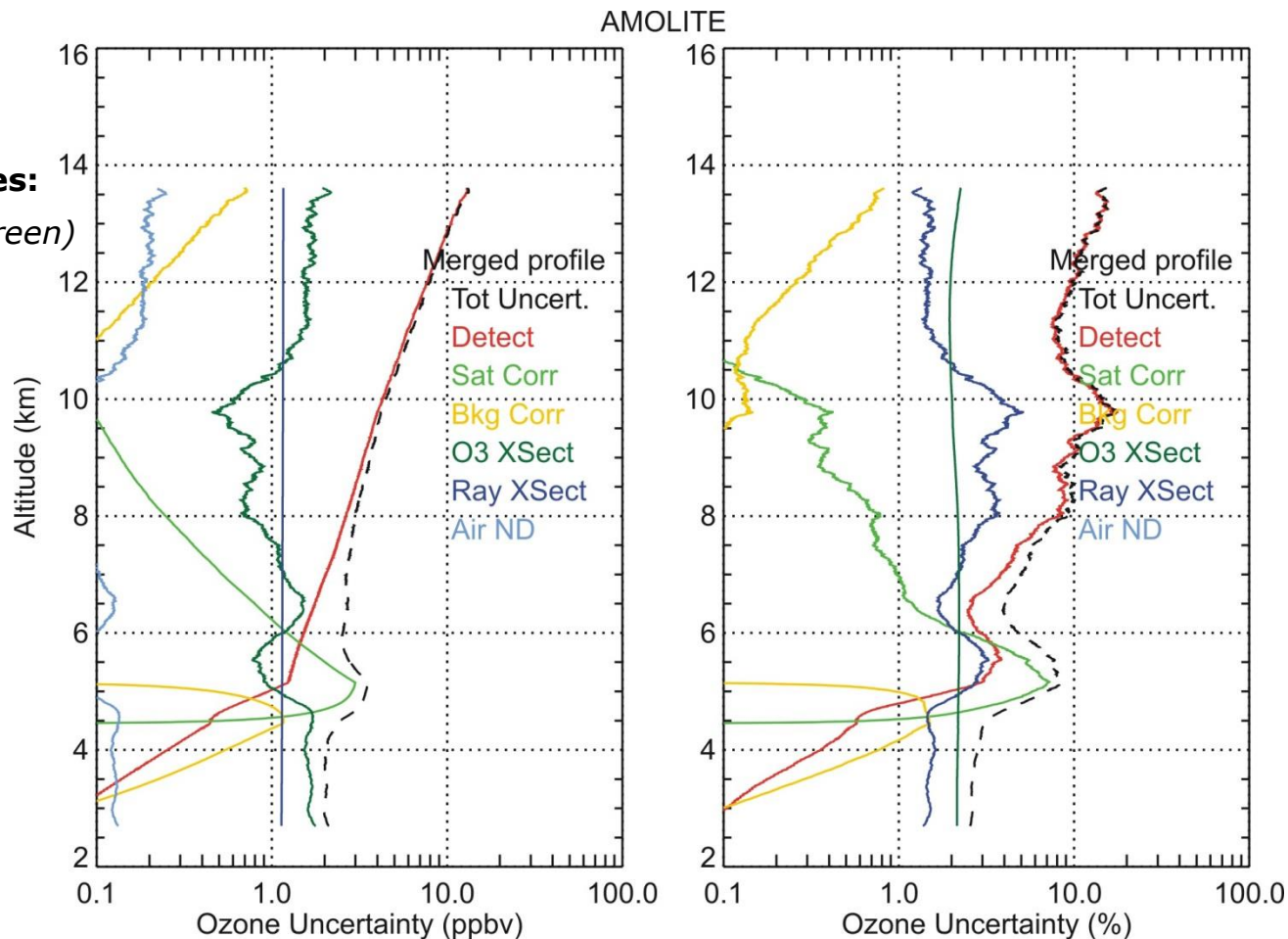


## AMOLITE case:

### Dominant uncertainty sources:

- Ozone cross-sections (dark green) below 4 km
- Saturation (light green) at 5 km
- Detection noise (red) 6 km and above
- All estimates are preliminary

**Black dash curves show combined total uncertainty**



**Uncertainty budgets for AMOLITE can be directly compared to other lidars by scrolling through next 4 slides**

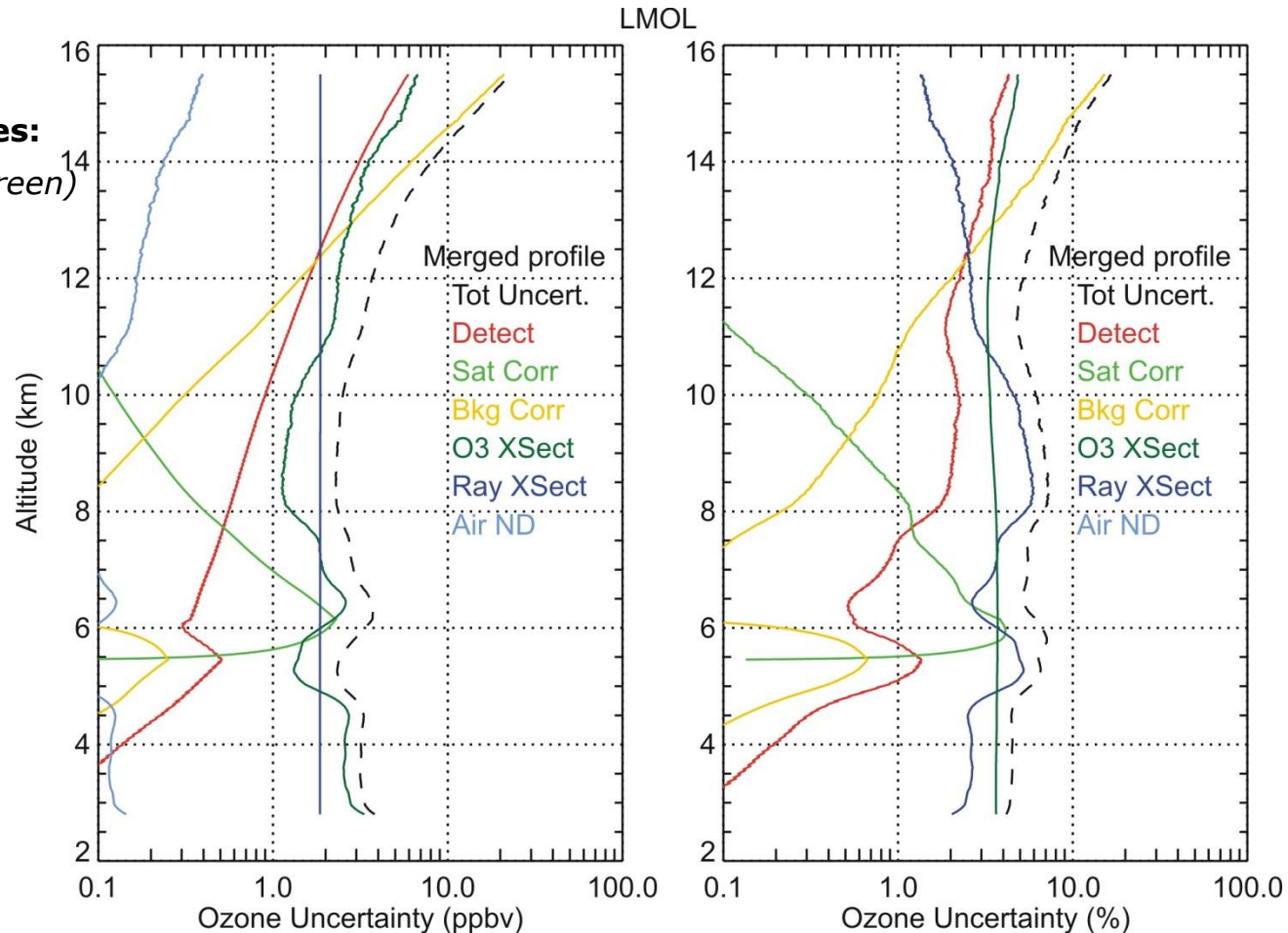


## LMOL case:

### Dominant uncertainty sources:

- Ozone cross-sections (dark green)  
Mainly below 5 km
- Saturation (light green)  
at 6 km
- Rayleigh extinction cross-section (blue)  
Below 12 km
- Background noise extraction (yellow)  
Above 12 km
- All estimates are preliminary

**Black dash curves show combined total uncertainty**



## TMT case:

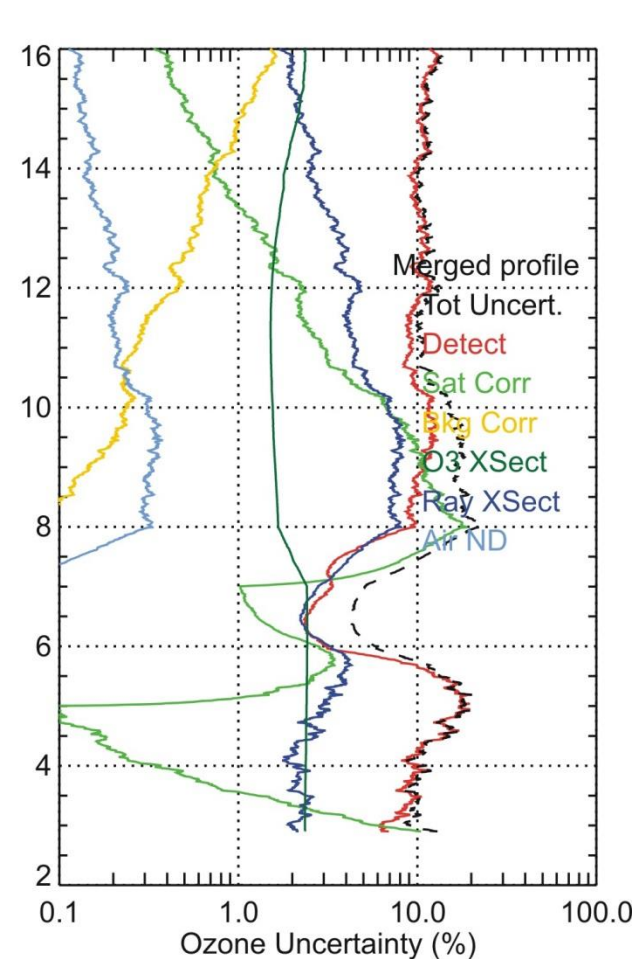
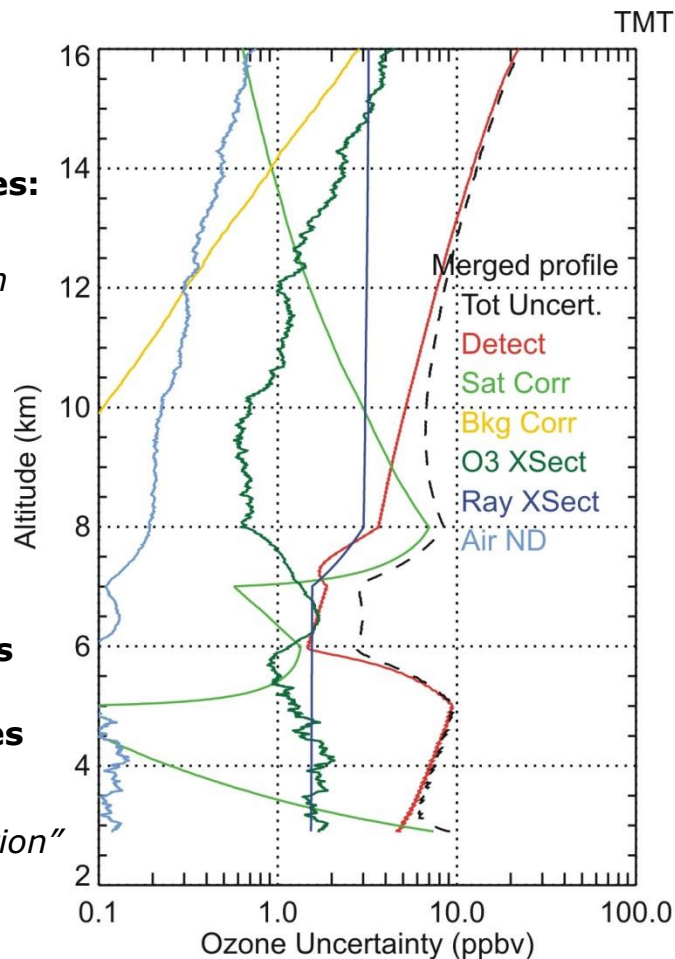
### Dominant uncertainty sources:

- Detection noise (red)  
Almost everywhere near 8 km
- Saturation (light green)  
at 8 km
- All estimates are preliminary

### Black dash curves show combined total uncertainty

**Total uncertainty for TMT is higher than other lidars, especially at lower altitudes**

- Lower STNR for near-field
- Inadequate "SCOOP resolution"



**→ SCOOP vertical resolution not well suited for TMT. Unlike the other TOLNet lidars, this lidar is optimized for altitudes above 4 km, nighttime and long-term monitoring**

## TROPOZ case:

### Dominant uncertainty sources:

- Saturation (light green) below 4 km
- Detection noise (red) Above 4 km
- All estimates are preliminary

**Black dash curves show combined total uncertainty**

